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CREATION OF SPHERICAL SHOCK WAVE IN THE ATMOSPHERE BY USING A SHOCK TUBE

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Polytechnic Institute of Brooklyn

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13. ABSTRACT

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ABSTRACT

The behavior of shock heated Argon expanding through a nozzle into the still atmosphere was investigated. It was found that any attempt to control or shape the emitted slug of hot gas to form a spherical bubble were unsuccessful, that a spherical weak shock propagated in front of the hot slug of gas, and that the flow was highly turbulent.

[†]This research was sponsored by the Advanced Research Projects Agency of the Department of Defense and was monitored by the U.S. Army Research Office-Durham under Contract No. DAHCO4-69-C-0077.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I. INTRODUCTION

There is a considerable interest in the laboratory simulation of diverse phenomena like the impingement of a hot plume on a surface, jet noise, explosions, thermals, etc. The understanding of most of these phenomena involve the study of the interaction of a hot slug of gas with its surroundings. Towards generating such an isolated slug of gas, shock tubes seem to provide interesting possibilities. The present report describes some preliminary results of an attempt at experimentally generating, on a laboratory scale, an isolated slug of hot gas which would be free to rise and expand in the atmosphere. Such a slug of gas would provide an ideal situation for studying turbulent mixing and entrainment in an explosion or an isolated thermal. By measuring the concentration distribution of an entrained specie or several species simultaneously, and possibly the temperature fluctuation profiles, a better understanding of the occurring phenomena could be obtained. As a diagnostic tool in this respect remote Raman spectroscopy appears to hold out great promise. In particular, since it can provide probeless measurements of several specie concentrations and their temperature simultaneously and instantaneously. Although it was desired to produce a generally spherical slug of gas, all efforts to control the shape of the gas bubble proved unsuccessful.

Earlier experiments on creation of spherical shock waves have been conducted by Boyer et al.[1] and Glass and Heuckforth[2] by breaking pressurized glass spheres. More recently Hamernik and Dosanjh[3] have examined the interaction of a two-dimensional heated fluid element with a controlled environment by exploding a copper wire in the center of the shock tube.

II. GENERAL DESCRIPTION OF THE EXPERIMENTS

The general idea behind the experiments was to use a shock tube to produce a limited slug of hot gas. The high pressure hot gas behind a reflected shock was allowed to expand through a nozzle into the atmosphere after breaking a thin diaphragm. The high pressure cold driver gas in the shock tube was cut off by a fast closing valve in the end of the shock tube. Various shaped nozzles were used in order to shape the slug of hot gas. Measurements of the shock velocity in the shock tube were made to determine the initial temperature, pressure and density of the hot gas. Outside the tube velocity of the expanding shock, created by the expanding bubble, was measured with the help of hot wires. No attempt was made as yet on utilizing the Raman scattering diagnostic technique. Schlieren and shadowgraph pictures were taken to study the flow pattern and shape of the expanding bubble

at various times. Two sets of experiments were conducted. In one case the hot gas was allowed to expand freely in the atmosphere through various shaped nozzles. In the second set of experiments the hot gas was made to fill and burst a balloon before expanding freely in the atmosphere.

III. DESCRIPTION OF EQUIPMENT

A diagram of the experimental setup is shown in Fig. 1. As shown a 1.0 inch i.d., pressure driven shock tube, 9 feet long, was used to produce the hot slug of gas. In the shock tube, Helium at 300 psi was used as the driver gas and Argon at 10 Torr was used as the driven gas. A simple double diaphragm technique using .010 inch mylar diaphragms was used to achieve controlled, reproducible shocks. The shock Mach number achieved with this setup was 6.8. The resulting temperature and pressure behind the reflected shock would be approximately 3000 Torr (58 psi) and 9600°K.

The shock tube itself was instrumented with three pressure transducers. The first was used to trigger the oscilloscopes and the other two were used to measure shock velocity in the tube. Typical oscilloscope traces from these transducers are shown in Fig. 2. No effort was made to filter the noise from these signals as they were only used to measure shock velocity which was easily obtained knowing the distance between the probes (7.8 inches) and measuring the time between responses. It may be noted, however,

that the pressure recorded behind the incident shock was approximately 12 psi as expected.

The shock tube was terminated by a .001 inch mylar diaphragm. This would burst under the pressure and high tempeatures of the reflected shock. In most of the tests this diaphragm was placed right behind a fast acting valve whose closing was initiated by the incident shock. The inertia of the valve would keep it open long enough for the hot gas behind the reflected shock to pass through it. Once closed, however, it would not allow the cold Helium driver gas to escape. At the valve, the tube diameter was reduced from 1.0 inch i.d. to .375 inches i.d., then expanded abruptly to .625 inches i.d. A diagram of this valve is shown in Fig. 3.

Following the thin mylar diaphragm was an elbow in which the flow was turned by 90°. This was necessary in order to obtain a symmetrical flow by avoiding the thermal effects and the effects of inertia on the hot gas flow and in addition, to obtain proper viewing for the optical system. Various nozzles could be put on this elbow section to allow investigation of their effects on the resulting jets. The five nozzles used are shown in Figs. 4a-e. In the tests in which the mylar diaphragm was mounted in the flat plate, the diaphragm just after the valve was omitted.

In the second series of experiments, balloons were placed over the nozzle to restrain the free expansion of the hot gas.

The two types of nozzles which were used in these tests are shown in Fig. 5. With the nozzle shown in Fig. 5a, the balloon had to be stretched to fit over it. It was felt that this could be causing the balloon to break prematurely at the base because of overstretching. Therefore, a second nozzle, shown in Fig. 5b was utilized with its outside diameter equal to the unstretched diameter of the neck of the balloon.

In the first series of tests without the balloon two hot wire probes were located several inches above the nozzle. These were used to measure the velocity of the shock and the gas coming out of the nozzle. These hot wire probes were run in the constant temperature mode and the amplifier voltage was recorded on an oscilloscope. Examples of the oscilloscope traces recorded are shown in Fig. 6.

Since the hot wires were run at higher than ambient temperatures, the first effect of the weak shock and flow behind it was to cool the wire. Later the hot gas arrived and heated the wires. This is seen in the traces as a steady increase in the amount of current needed to maintain the wire at constant temperature followed by a sharp drop. The velocities are easily determined knowing the probe separation and measuring the times between their responses. Measurements of the times between the initial responses of the hot wire probes were made at various positions out to 21 inches from the nozzle. The results are shown in Fig. 7 and indicate a

wave traveling at a constant velocity of 1170 ft./sec. or at Mach 1.03.

A better understanding of the experiments was obtained from the shadow and Schlieren photographs, however. This system used a spark light source and was synchronized with the shock tube to observe the flow from the orifice at any precisely preset instant of time. The synchronization was achieved by using the variable delay system of a Tektronix 565 oscilloscope, to initiate a short duration spark which provided the light source for the Schlieren and shadowgraph. Two 12 foot focal length, 12" diameter front surface parabolic mirrors were used to collimate the light and focus the image of the flow field on a Polaroid film. Since discharges in the atmosphere are inherently unstable, a steady flow of Argon, injected into the region of the spark gap helped to stabilize the spark used as the light source.

Examples of the Schlieren photographs are shown in Figs. 8 and 9 and examples of the shadowgraphs in Figs. 10 and 11. It is evident that the quality of the shadowgraphs is better than that of the Schlieren. This can be attributed to the instability of the spark system, and the general ambient turbulent noise level in the space between the collimating and focussing mirrors.

IV. RESULTS

Shock waves of Mach number 6.8 were produced in Argon. Hot

Argon formed behind the reflected shock was allowed to expand through a nozzle. The shadow and Schlieren pictures show a number of interesting features of the flow under investigation.

1. Any attempt to control or shape the emitted slug of gas to form a spherical bubble was unsuccessful.

2. Irrespective of the nozzle shape, temperature, density and duration of the gas flow, a spherical weak shock propagated in front of the hot gas slug.

It was generally found that the flow of hot Argon is highly turbulent regardless of the shape of the nozzle. In addition to the fine turbulent structure, there were regions of intermittancy in the boundary between the jet and the surrounding atmosphere. Hot wire responses also indicate intermittant flow with periods of cooling during the flow of hot gas.

A striking feature was the spherical shock wave produced ahead of the expanding hot Argon. Hot wire measurements show it to be a weak shock traveling at a constant velocity at about Mach number 1.03. These results agree essentially with the results obtained by Glass and Heuckforth[2]. The shape of the expanding hot gas could not be inferred from the shock shape which was always spherical despite the highly irregular shape of the slug driving it.

Finally, it should be remarked that the optical observation as obtained through shadowgraph or Schlieren photographs reveal

a standing vortex pattern at the exit of the nozzle irrespective of their shape. While the presence of the vortex rings at the exit can be explained in terms of the vorticity in the boundary layer in the nozzle the long time behavior of the vortex rings and their disintegration in time is not well-understood.

V. REFERENCES

1. Boyer, D.W., Brode, H.L., Glass, I.I. and Hall, J.G.: Blast from a Pressurized Sphere. University of Toronto Institute of Aerophysics, Report No. 48, 1958.
2. Glass, I.I. and Heuckforth, L.E.: Head-On Collision of Spherical Shock Waves. Phys. Fluids, 2, 5, September 1959.
3. Hamernik, R.P. and Dosanjh, D.S.: Shock Induced Dynamics of a Low-Density Heated-Fluid Element. Phys. Fluids, 15, 7, July 1972.

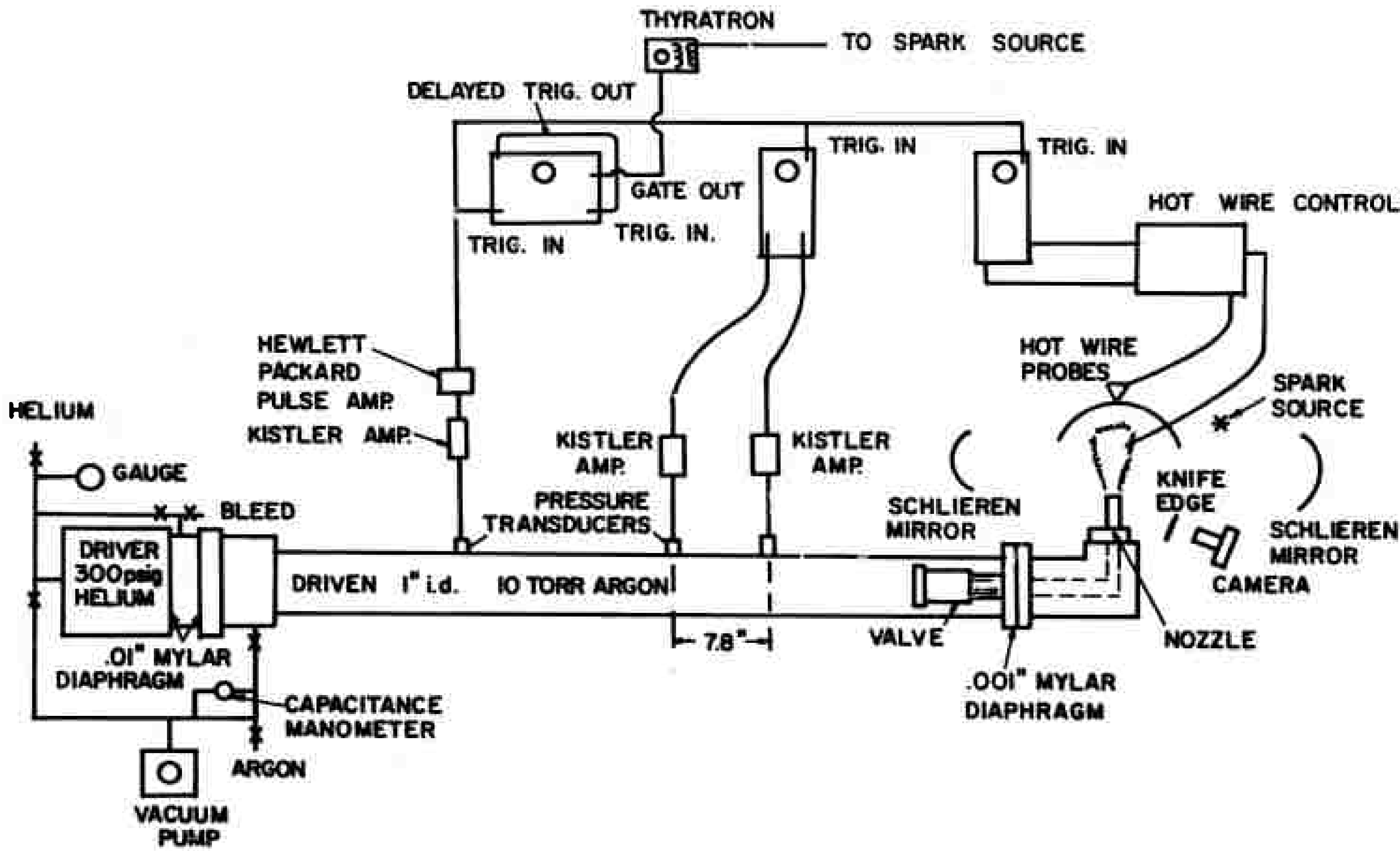
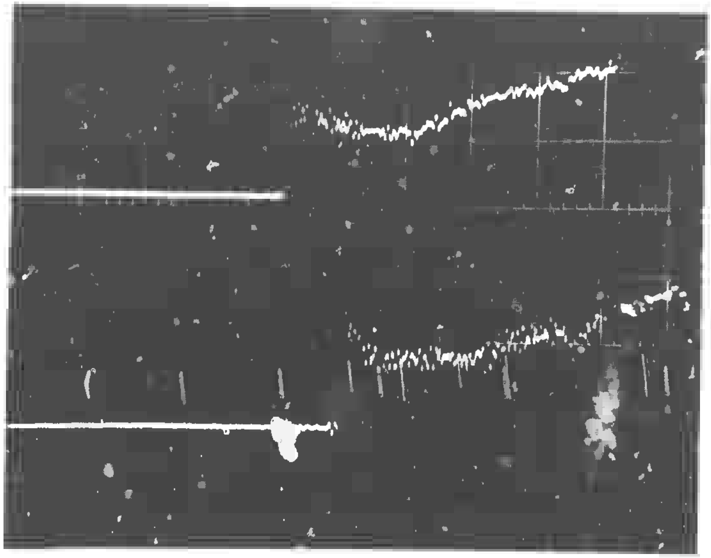


FIG. 1 EXPERIMENTAL SET UP



10 psi/DIV.

TIME → 100 μ sec./DIV.

FIG. 2 TYPICAL RECORDING FROM PRESSURE TRANSDUCERS

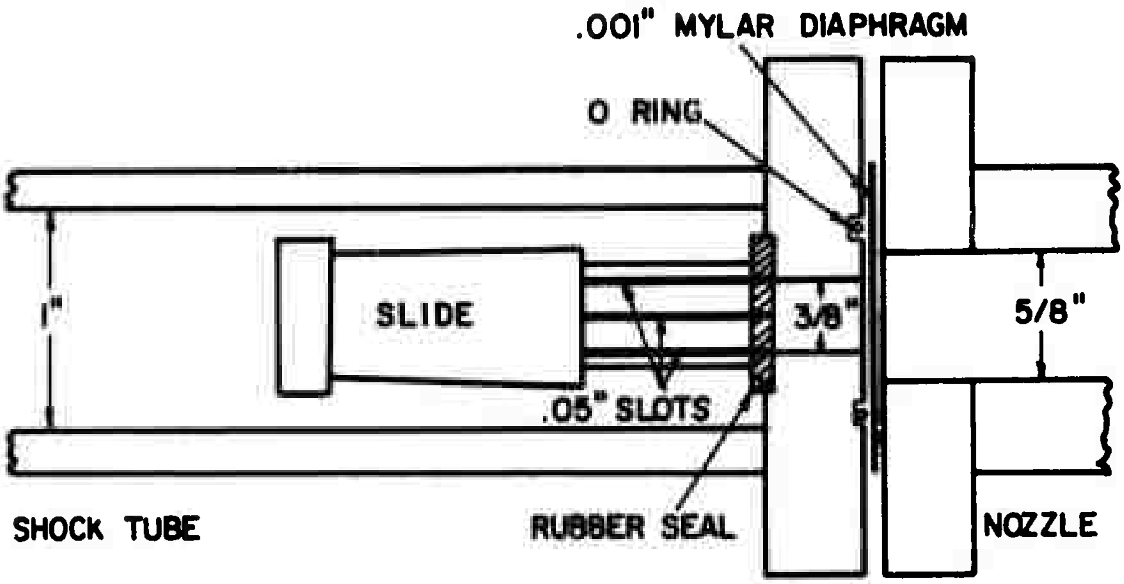


FIG. 3 SLIDE VALVE IN OPEN POSITION - DRAWINGS NOT TO SCALE

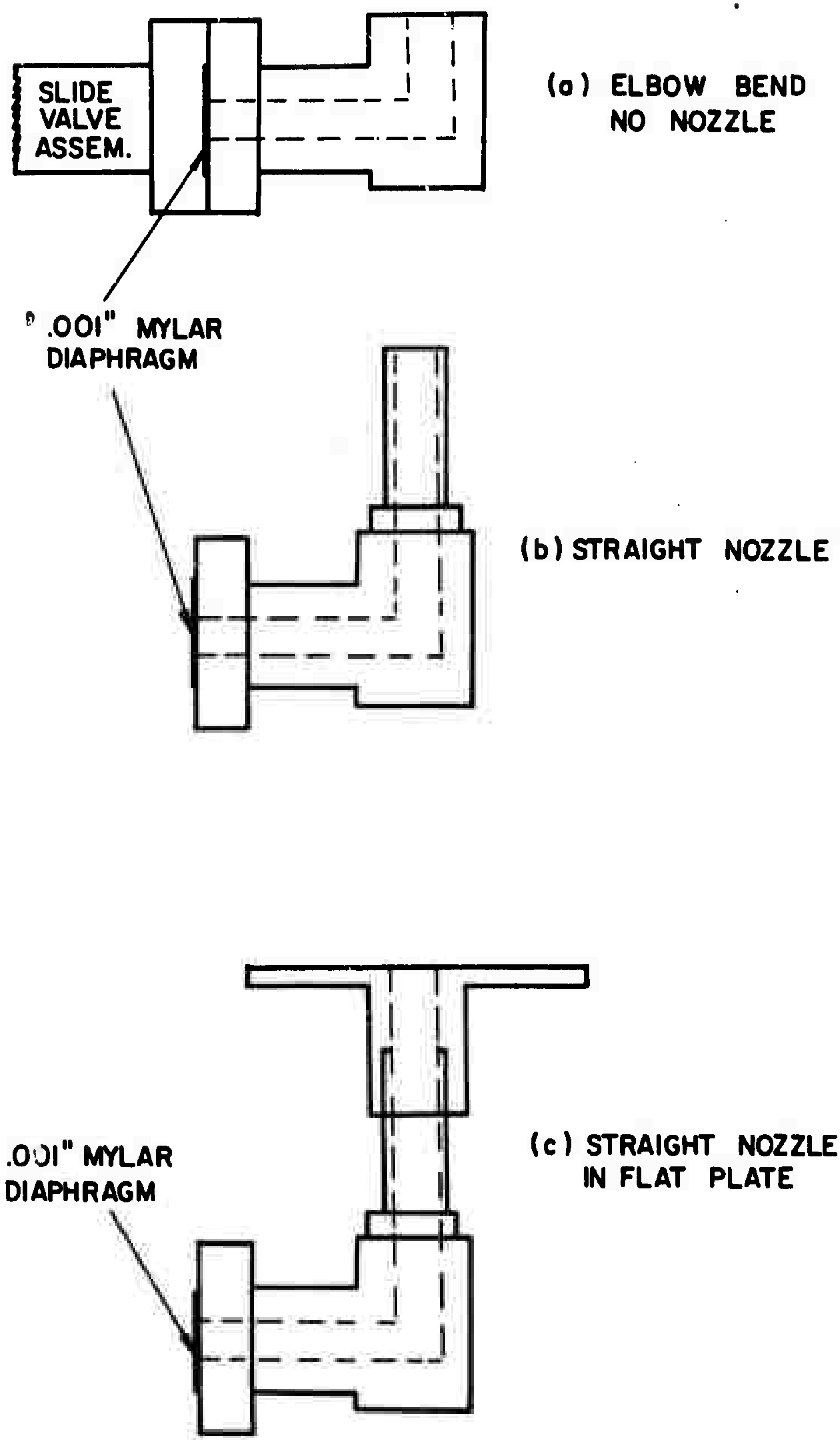
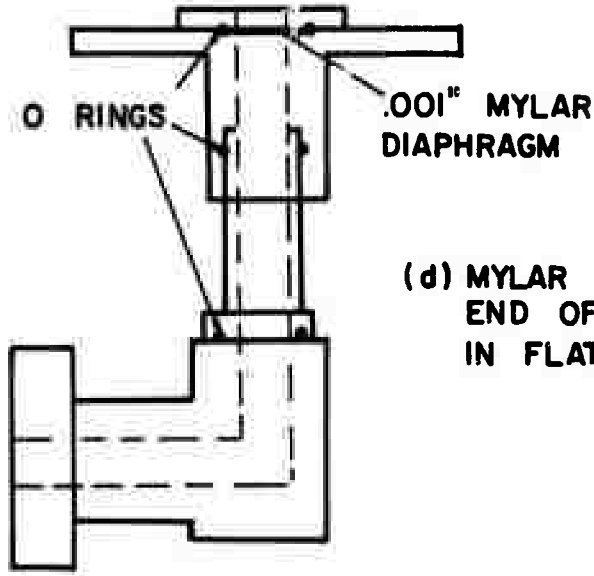
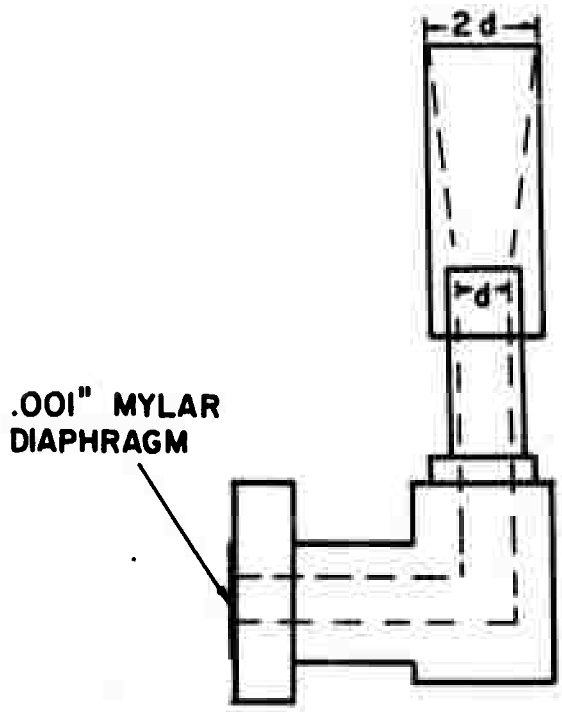


FIG. 4 NOZZLE CONFIGURATIONS - DRAWINGS NOT TO SCALE



(d) MYLAR DIAPHRAGM AT END OF STRAIGHT NOZZLE IN FLAT PLATE



(e) 2:1 DIVERGENT NOZZLE

FIG. 4 NOZZLE CONFIGURATIONS - DRAWINGS NOT TO SCALE

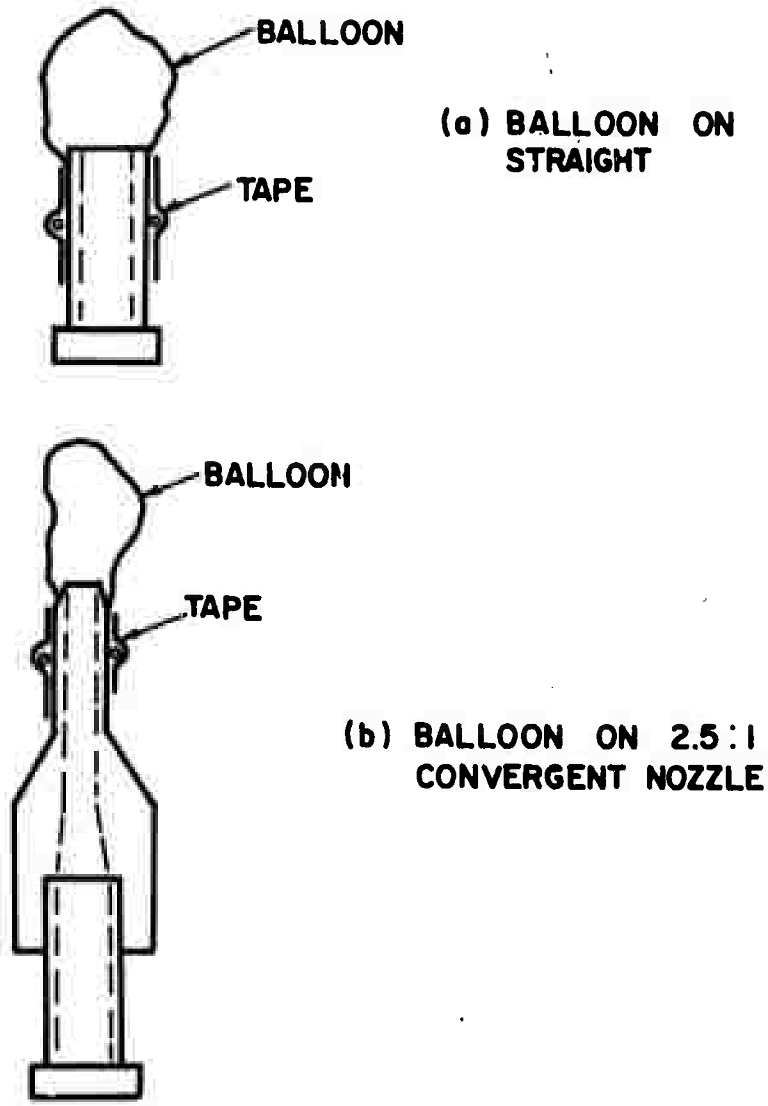


FIG. 5 NOZZLE CONFIGURATIONS FOR BALLOON BURST TESTS

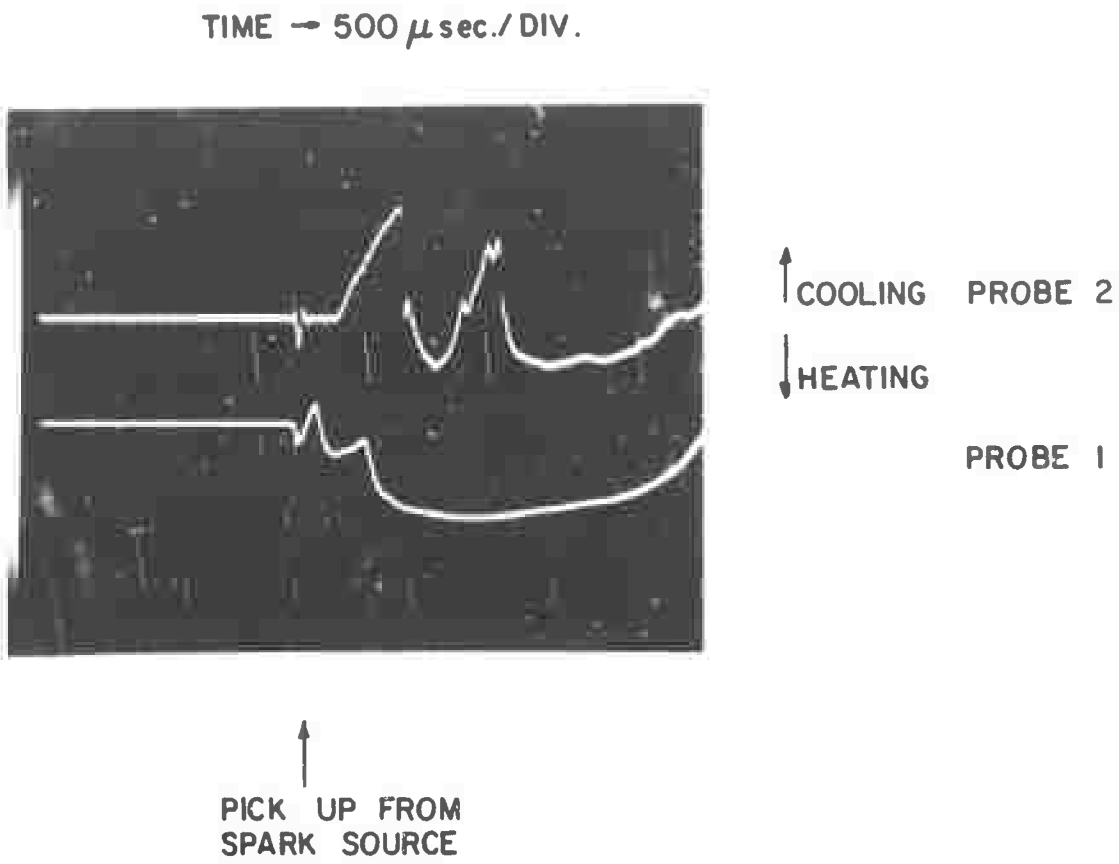


FIG. 6 TYPICAL RECORDING FROM HOT WIRE PROBES

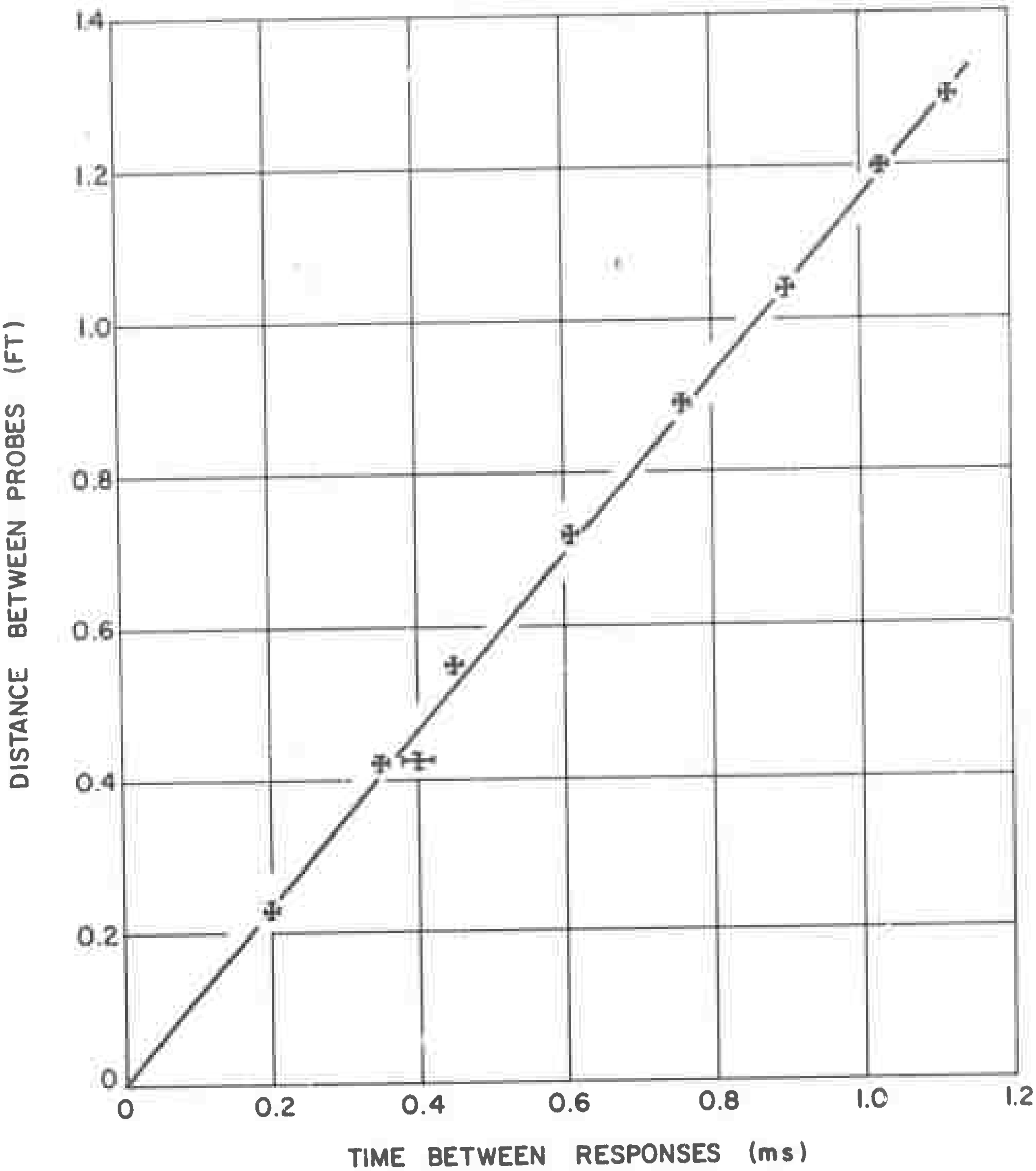
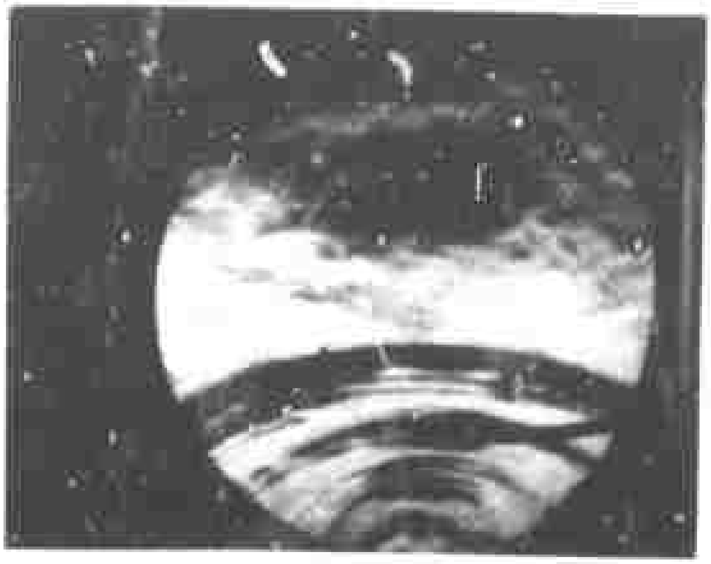


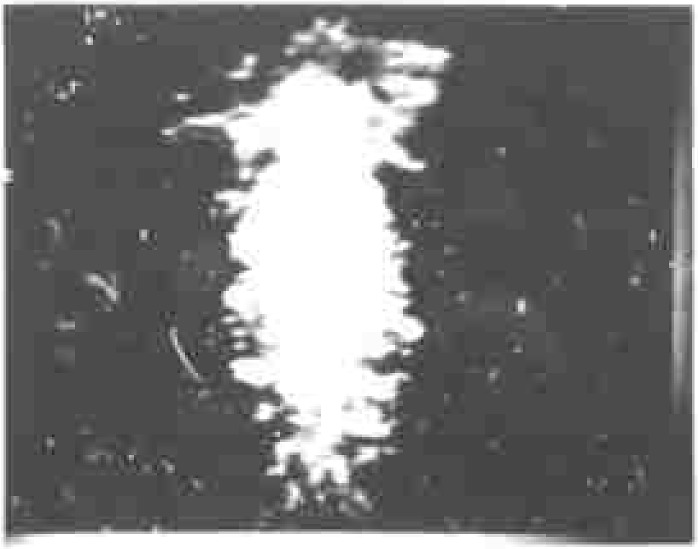
FIG. 7 TIME BETWEEN HOT WIRE RESPONSES AS A FUNCTION OF DISTANCE BETWEEN PROBES



(a) 2.0 ms delay

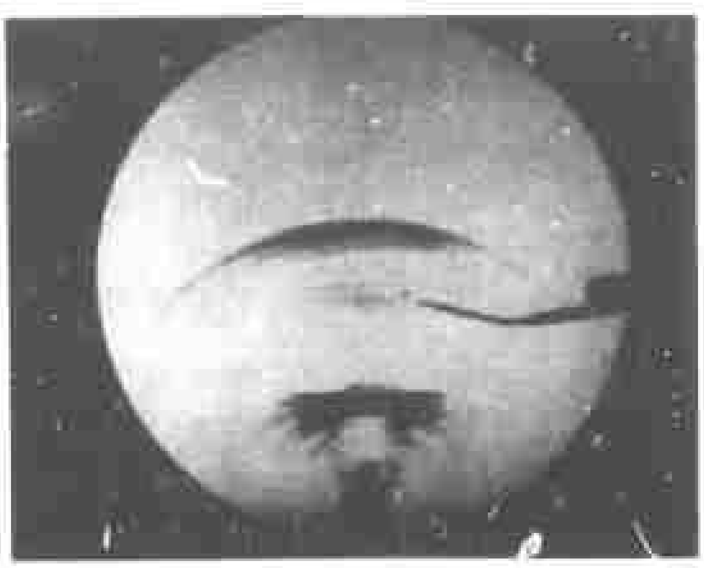
(b) 2.2 ms delay

Fig. 8 Schlieren Photographs- Flow With No Nozzle

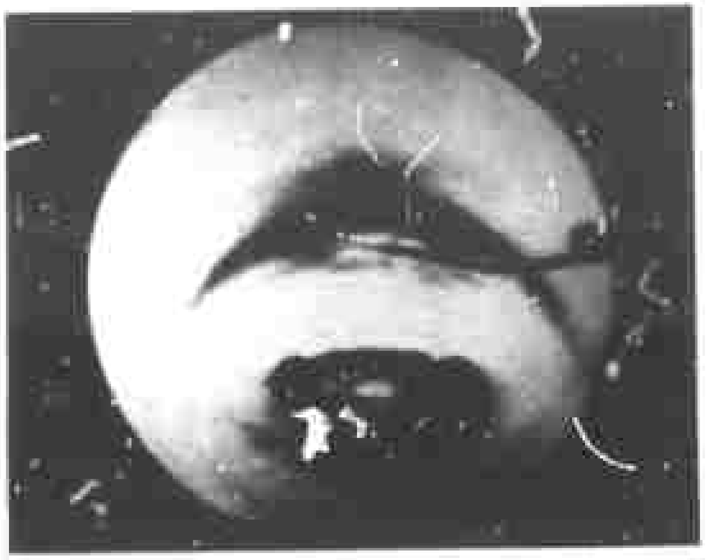


(c) 3.[illegible] ms delay

Fig. 8 Schlieren Photographs - Flow With No Nozzle

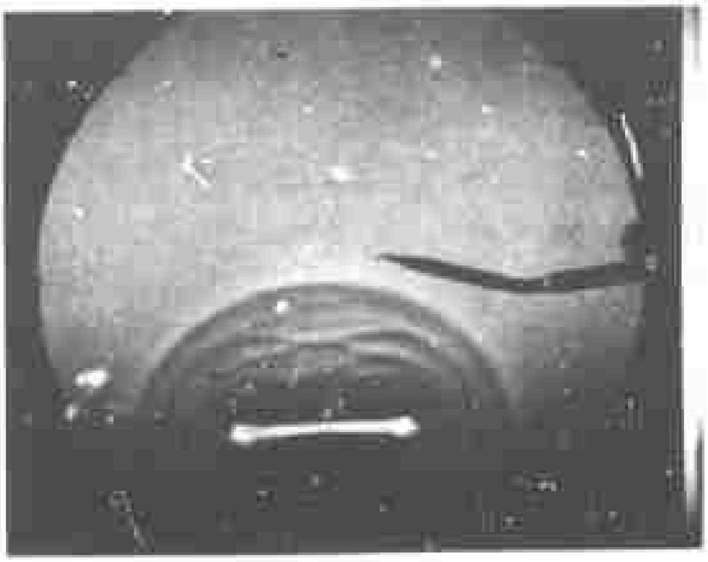


(a) Straight Nozzle

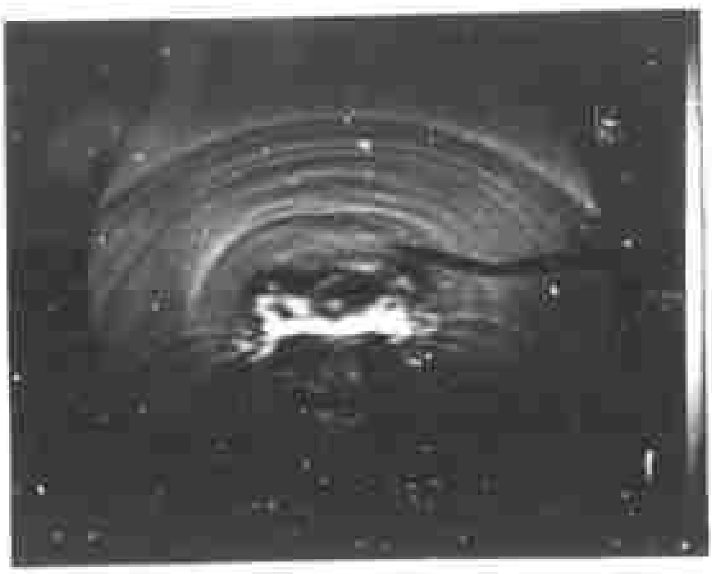


(b) Divergent Nozzle

Fig. 9 Schlieren Photographs - Flow From Straight and Divergent Nozzles

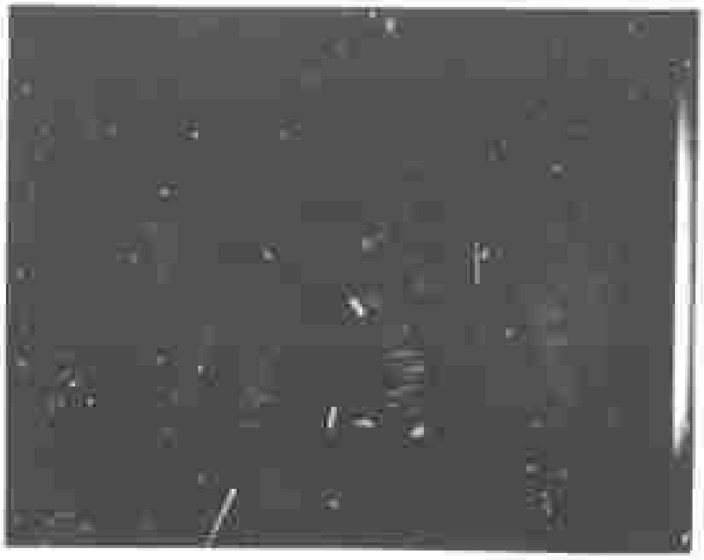


(a) Divergent Nozzle

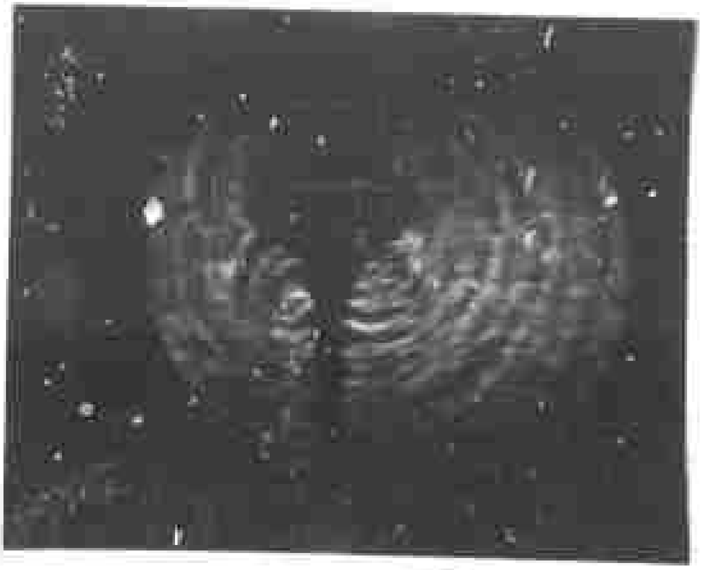


(b) Nozzle in Flat Plate

Fig. 10 Shadowgraphs - Flow From Divergent Nozzle and Straight Nozzle in Flat Plate



(a) Straight Nozzle



(b) Convergent Nozzle

Fig. 11 Shadowgraphs - Balloon Bursts